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Properties of Low-Redshift Damped Lyman Alpha Galaxies

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Abstract. Images of five QSO fields containing six damped Ly α (DLA) systems at redshifts $0.09 < z < 0.53$ are presented. Identifications for the DLA galaxies giving rise to the DLA systems are made. The observed and modeled characteristics of the DLA galaxies are discussed. The DLA galaxies have impact parameters ranging from < 4 kpc to ≈ 34 kpc and luminosities in the range $\approx 0.03L^*$ to $\approx 1.3L^*$. Their morphologies include amorphous low surface brightness systems, a probable dwarf spiral, and luminous spirals.

1. Introduction

Since damped Ly α systems (DLAs) identified in QSO absorption-line surveys trace the bulk of the observable neutral gas in the Universe from high to low redshift ($4 > z > 0$), they are important probes of galaxy formation and evolution. In principle, their observed cosmic evolution is the net result of the global processes which give rise to conversion between the HII, HI, and H₂ phases. Thus, while galaxy populations selected in optical/IR surveys can be used to study the star formation history of the Universe, DLA galaxies identified through follow-up imaging work, i.e., by virtue of their gas cross-sections, reveal the HI gas production and consumption history of the Universe. At present, only at low redshift can we easily study and compare these populations. With the discovery of a significant number of low-redshift ($z < 1.65$) DLAs (Rao & Turnshek 2000), we are now in a position to comprehensively study the properties of the DLA galaxies that give rise to them. Le Brun et al. (1997) imaged a sample of six

low-redshift DLA fields with HST, and found that DLA galaxies span a range of luminosities and morphologies. Here, we present ground-based imaging results of five QSO fields with six DLAs and confirm their results. Overall, the DLA galaxy population at low-redshift contains a significant number of dwarf and/or low surface brightness (LSB) galaxies. Results on two DLAs in the Q0738+313 field were presented in Turnshek *et al.* (2001), and we summarize them here. In Turnshek, Rao, & Nestor (2001, these proceedings), we compare the properties of low-redshift DLA galaxies with the population of gas-rich galaxies in the local Universe. Throughout this paper, we use $H_0 = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $q_0 = 0.5$, and $\Lambda = 0$.

2. Observations

Optical and infrared images of the five QSO fields discussed here were obtained during the period between November 1997 and September 2000. The optical images were obtained at the MDM Observatory 2.4m Hiltner Telescope on Kitt Peak using the 1024×1024 Templeton CCD ($0.285'' \text{ pixel}^{-1}$) and by the queue observing team using a 1024×1024 Tektronix CCD ($0.195'' \text{ pixel}^{-1}$) on the 3.5m WIYN Telescope on Kitt Peak. The infrared images were obtained at the 3.0m NASA IRTF on Mauna Kea using NSFCAM, a 256×256 InSb detector array ($0.30'' \text{ pixel}^{-1}$) and the 3.58m ESO NTT on La Silla using a 1024×1024 HgCdTe detector array ($0.292'' \text{ pixel}^{-1}$). The images were reduced using the usual procedures and standard star observations were used to calibrate the photometry.

3. SED and Isophotal Template Fits

In order to explore the properties of three of the identified DLA galaxies, spectral energy distribution (SED) templates were fitted to the available multiband photometric data. Using the GISEL99 (Bruzual and Charlot) library of SEDs, stellar populations corresponding to eleven different ages (spanning 0.001 to 12.0 Gyrs) derived from a Salpeter IMF were combined in all possible permutations of two different ages. Each permutation was then combined with eleven different weighting schemes. The resulting 605 templates were subjected to a Calzetti (2000) reddening law with eleven possibilities for the amount of dust (spanning $0.0 \leq A_V \leq 3.6$). Each of the eleven sets (corresponding to a given amount of dust) was evaluated with a principal component analysis routine in order to extract eigen-spectra for each set. The template built from the eigen-spectra giving the smallest chi-square when compared to the DLA galaxy photometry was then mapped back to the original set of templates to determine the ages, reddenings, and stellar populations that best fit the DLA galaxy photometry. The results are summarized in §4 and given in Table 1 and Figure 1a.

We also investigated the radial light profiles of the DLA galaxies. Exponential and $r^{1/4}$ profiles convolved with a Gaussian to model the effects of seeing were compared to the observed profiles. It was not possible to fit isophots for the three DLA galaxies that were classified as LSB/amorphous and the results for one of the luminous (probable) spirals were inconclusive. The results for two

of the identified DLA galaxies are summarized in §4 and presented in Table 1 and Figure 1b.

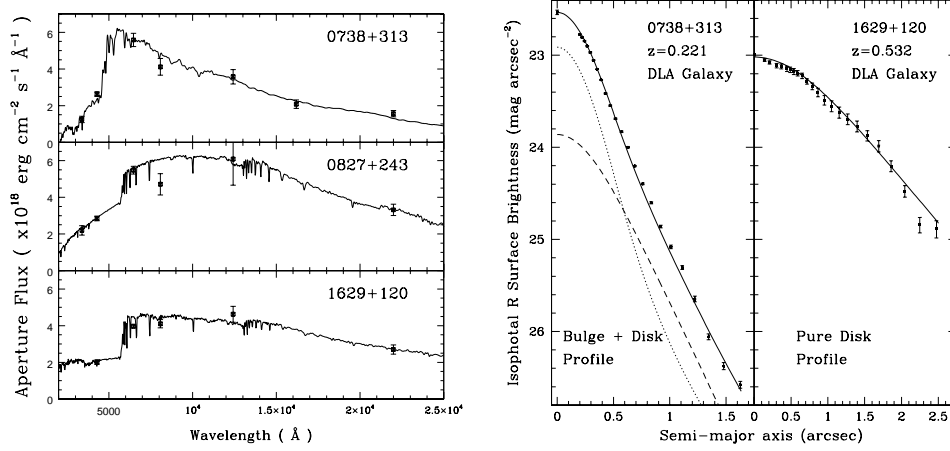


Figure 1. The left three-panel figure shows best-fit two-burst templates for three DLA galaxies. See Table 1 for details of each template. Data points are UBRIJHK photometric measurements from the MDM, WIYN, and IRTF telescopes. The right two-panel figure shows model fits to the R-band radial light profiles of two DLA galaxies. In the left panel is the fit for the $z = 0.221$ DLA galaxy towards Q0738+313. The interior isophots are dominated by an $r^{1/4}$ (bulge) profile while the outer isophots are dominated by an exponential (disk) profile. In the right panel is the fit for the $z = 0.532$ DLA galaxy towards Q1629+120. A purely exponential (disk) profile is a good fit to these data.

4. DLA Galaxies

Figures 2–6 show the five DLA QSO fields that contain six DLA galaxies. Three DLA galaxies have a confirmed slit redshift and are labeled in the corresponding figure. Identifications are also made for the other three DLAs. It should be kept in mind, however, that the identification of a DLA galaxy is never fully certain. While one can be fairly confident with an identification when the galaxy appears to be isolated and at low impact parameter to the sightline, it is always possible that another faint galaxy at low impact parameter might be hidden in the PSF of the QSO. See Turnshek, Rao, & Nestor (2001, these proceedings) for further discussion. We consider the identifications and properties of the six DLA galaxies below.

The sightline towards **Q0738+313** contains two low-redshift DLAs at $z = 0.091$ and $z = 0.221$. The $z = 0.091$ absorber is identified with the LSB galaxy at low impact parameter (see Figure 2). A very red ($R-K > 5.5$) “arm”-like feature can be seen in the infrared images to the east of the QSO, suggestive of spiral structure. The “jet”-like feature to the west, however, is bluer ($R-K \approx 3.2$) which suggests the possibility of an irregular/interacting system. The total observed extent of the system is $\approx 12 - 16$ kpc and the upper-limit on its luminosity is $\approx 0.13L^*$. The $z = 0.221$ absorber is an early type dwarf ($0.1L^*$) at an impact parameter of 20 kpc. Its colors are consistent with star

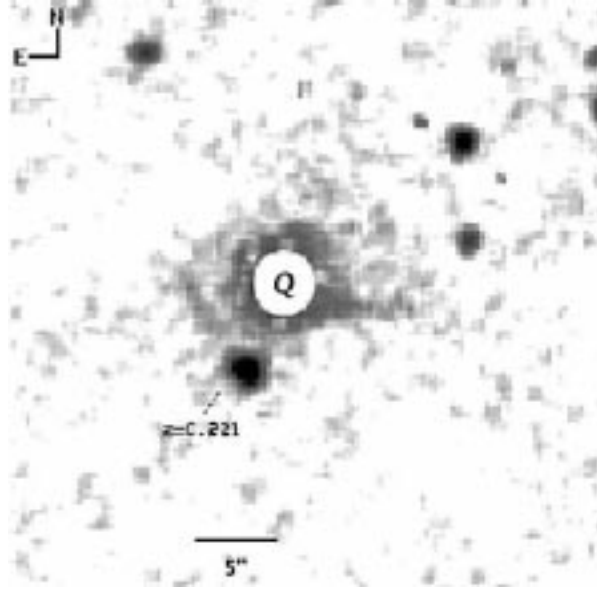


Figure 2. The IRTF K band image of the Q0738+313 field. The light at the position of the QSO (labeled Q) has been subtracted. The DLAs are at redshifts $z = 0.091$ and $z = 0.221$. On the image, 5 arcsec corresponds to 9 kpc at $z = 0.091$ and 17.5 kpc at $z = 0.221$. The $z = 0.091$ DLA is assumed to be the LSB galaxy at low impact parameter surrounding the sightline (Turnshek et al. 2001).

formation models suggesting its formation epoch was less than a few Gyr ago, i.e., $z_f \approx 0.3 - 0.9$ (Figure 1a). Its isophotal light distribution indicates a combination of $r^{1/4}$ bulge-like and exponential disk-like components (Figure 1b). These systems are discussed in more detail in Turnshek et al. (2001).

The sightline towards **Q0827+243** contains a DLA at $z = 0.525$. The luminous ($\approx 1.3L^*$) galaxy 6 arcsec, or 34 kpc, to the east of the sightline is identified as the DLA galaxy (see Figure 3). Although isophotal profile fitting was inconclusive, the colors are consistent with star formation models suggesting recent star formation and the presence of significant dust (Figure 1a). The galaxy is likely a late-type object and possibly a spiral, although this remains to be confirmed.

The sightline towards **Q0952+179** contains a DLA at $z = 0.239$. The structure seen to the east and southwest of the QSO is the only evidence for an absorber and therefore is identified as the DLA galaxy (see Figure 4). The galaxy is inferred to be LSB, but its faintness and small impact parameter (< 7 kpc) make it difficult to tell whether it is a single LSB galaxy or a patchy/irregular system. A PSF subtraction of the light from the QSO leads to the estimated lower-limit on its luminosity of $\approx 0.03L^*$.

The sightline towards **Q1127-145** contains a DLA at $z = 0.313$. This DLA is associated with the north-south elongated patchy/irregular LSB structure ≈ 3.5 arcsec to the west of the sightline (see Figure 5). A PSF subtraction of

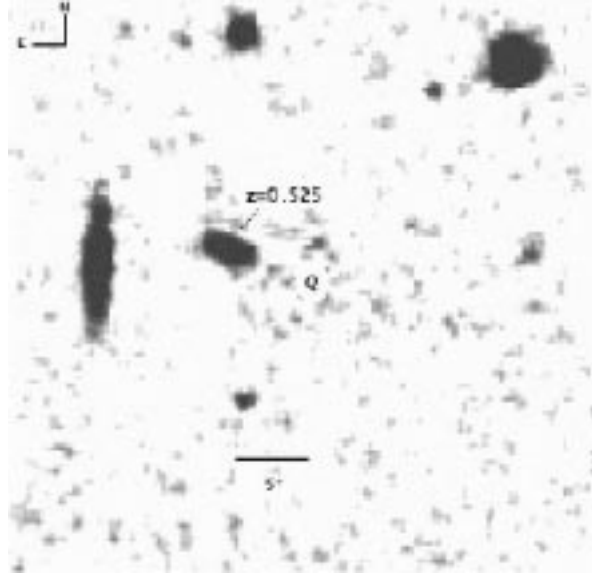


Figure 3. IRTF K band image of the Q0827+243 field. The light at the position of the QSO (labeled Q) has been subtracted. The DLA redshift is $z = 0.525$. On the image, 5 arcsec corresponds to 28 kpc at the DLA redshift.

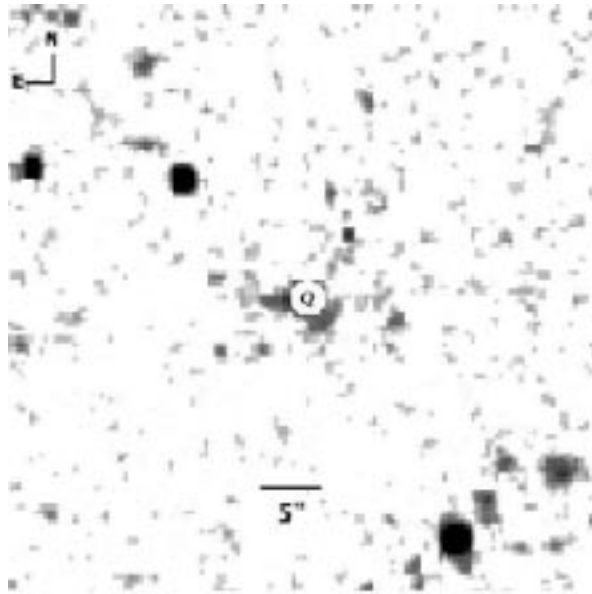


Figure 4. The NTT J band image of the Q0952+179 field containing a $z = 0.239$ DLA absorber. The light at the position of the QSO (labeled Q) has been subtracted. The LSB structure to the east and southwest of the sightline is identified as the absorber given the absence of brighter objects near the sightline. On the image 5 arcsec corresponds to 18.5 kpc at $z = 0.239$.

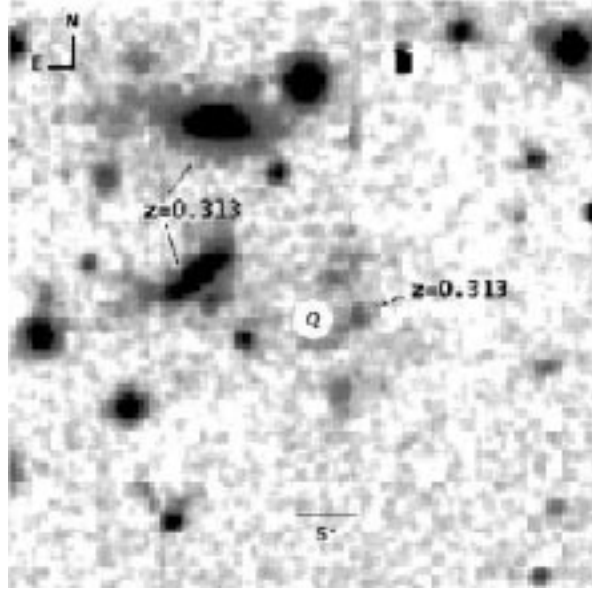


Figure 5. The NTT J band image of the Q1127+145 field containing a $z = 0.313$ DLA absorber. The light at the position of the QSO (labeled Q) has been subtracted. The LSB structure extending north-south and to the west of the QSO is identified as the absorber. On the image, 5 arcsec corresponds to 22 kpc at the DLA redshift.

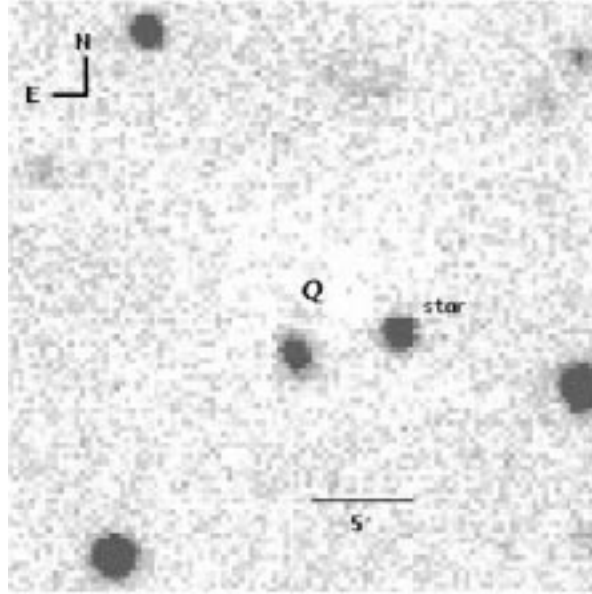


Figure 6. IRTF K band image of the Q1629+120 field containing a $z = 0.532$ DLA absorber. The light at the position of the QSO (labeled Q) has been subtracted. The luminous galaxy to the south of the QSO is identified as the DLA galaxy. On the image, 5 arcsec corresponds to 28 kpc at the DLA redshift.

the light from the QSO gives a luminosity of $\approx 0.05L^*$ for the DLA galaxy. Two other bright objects in the field are at the absorption redshift as well; evidently there is a galaxy group or cluster at this redshift. The LSB structure is identified as the DLA absorber due to its smaller impact parameter (< 10 kpc as opposed to > 36 kpc for the luminous galaxies).

The sightline towards **Q1629+120** contains a DLA at $z = 0.532$. The luminous ($\approx 1.1L^*$) galaxy 3 arcsec, or 17 kpc, to the south of the sightline is the only resolved object in the field (see Figure 6) leading to the identification of this object as the DLA galaxy. A pure exponential law fits the isophotal light profile of this object well, and SED template fits to its colors imply recent star formation and the presence of dust (Figures 1a and 1b). Taken together, the observed and modeled characteristics strongly imply that this DLA galaxy is a luminous late-type spiral.

Table 1: DLA Galaxy Characteristics

QSO	0738+313	0738+313	0952+179	1127-145	0827+243	1629+120
z_{abs}	0.091	0.221	0.239	0.313	0.525	0.532
N_{HI} (cm^{-2})	1.5×10^{21}	7.9×10^{20}	2.1×10^{21}	5.1×10^{21}	2.0×10^{20}	2.8×10^{20}
L^a	$\approx 0.08 L^*$	$\approx 0.10 L^*$	$\gtrsim 0.03 L^*$	$\approx 0.05 L^*$	$\approx 1.3 L^*$	$\approx 1.1 L^*$
b^b (kpc)	< 4	20	< 7	< 10	34	17
Morphology	LSB	compact dwarf	patchy/ irr LSB	patchy/ irr LSB	possible spiral	spiral
Best-Fit Model Template						
Burst Ages ^c	...	80% 0.6 Gyr 20% 4.0 Gyr	...	...	74% 0.001 Gyr 26% 0.01 Gyr	90% 0.2 Gyr 10% 0.001 Gyr
A_V	...	0.4	...	...	3.6	2.0
Isophotal Fit	...	disk + bulge	...	...	...	disk

^aBased on infrared photometric data.

^b $b \equiv$ impact parameter.

^cFraction by burst-mass, best-fit two-burst model.

5. Summary

The DLA galaxies presented here span a wide range of observed characteristics (see Table 1). The neutral hydrogen column densities range from the minimum value for a classical DLA system ($N_{HI} = 2 \times 10^{20}$ atoms cm^{-2}) up to 5.1×10^{21} atoms cm^{-2} . Similarly, the luminosities range from $\approx 0.03L^*$ to $1.3L^*$. The largest impact parameter in this small sample is 34 kpc, while three of the systems have impact parameters less than 10 kpc. The morphologies likewise vary. One of the luminous galaxies is a spiral, while the other is a possible spiral; three are underluminous LSB galaxies with patchy/irregular structure; and one is a compact dwarf galaxy. Thus, the range in DLA galaxy properties seen here is consistent with previous findings that they are drawn from a variety of galaxy types (Le Brun et al. 1997; Steidel et al. 1997; Rao & Turnshek 1998; Turnshek et al. 2001).

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